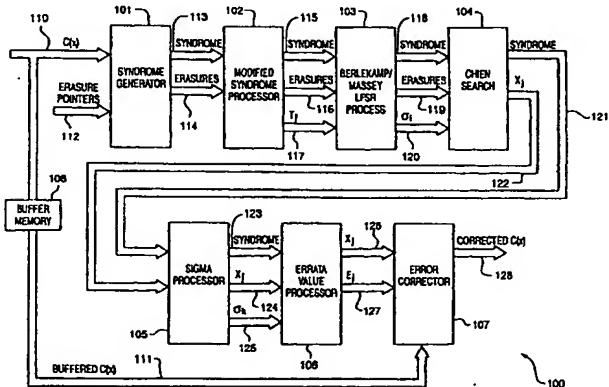




INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : H03M 13/15		A1	(11) International Publication Number: WO 00/57561 (43) International Publication Date: 28 September 2000 (28.09.00)
<p>(21) International Application Number: PCT/US00/07675</p> <p>(22) International Filing Date: 22 March 2000 (22.03.00)</p> <p>(30) Priority Data: 09/274,406 23 March 1999 (23.03.99) US</p> <p>(71) Applicant: STORAGE TECHNOLOGY CORPORATION [US/US]; One StorageTek Drive, MS-4309, Louisville, CO 80028-4309 (US).</p> <p>(72) Inventor: BOYER, Keith, G.; 13450 Jackson Place, Thornton, CO 80421 (US).</p>			<p>(81) Designated States: JP, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).</p> <p>Published <i>With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i></p>

(54) Title: PIPELINED HIGH SPEED REED-SOLOMON ERROR/ERASURE DECODER



(57) Abstract

The pipelined high speed Reed-Solomon error/erasure decoder processes multiple code words in a pipelined fashion. The pipelined high speed Reed-Solomon error/erasure decoder is designed to process Reed-Solomon encoded words that have been corrupted in a digital system by processing errors as well as erasures through a simple iterative modified syndrome process. The iterative nature of this method provides for limited computational effort at each step of the pipeline. This allows the pipelined high speed Reed-Solomon error/erasure decoder to easily handle full or shortened Reed-Solomon codes, as well as parallel processing to achieve higher data rates. The iterative modified syndrome process is one of the pipelined steps. It relieves the erasure pre-shifting burden from the Berlekamp/Massey synthesis process, which reduces the number of cycles required at that stage of processing. The decoder proceeds classically with a Chien Search for any remaining error locations. This approach allows the pipelined high speed Reed-Solomon error/erasure decoder to relay early information on all error locations. The final stage of the decoding process is a parallel, iterative solution to Forney's equation for the calculation of the error magnitudes.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakhstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

Pipelined High Speed Reed-Solomon Error/Erasure Decoder**Field of the Invention**

This invention relates to a system that decodes a class of multiple error correcting codes known as Reed-Solomon Codes, which are typically used within 5 digital communication systems to detect corrupted data contained in the digital transmission and correct these corrupted data. As part of the Reed-Solomon error correcting process, redundancy is added to the transmitted data, such that upon receipt of a data transmission, the possibly corrupted data and redundancy are mathematically processed to correct the corrupted data in the data transmission.

10

Problem

It is a problem in high speed decoding of multiple error correcting codes, known 15 as Reed-Solomon codes, with or without erasure pointers, to reduce the number of computational steps that are required at each stage of decoding. It is, likewise, a problem to reduce the number of combinatorial operations that are required to exchange data between any two hardware registers that are operational within the 20 Reed-Solomon decoder.

Reed-Solomon Codes are used within digital communication systems, such as 25 fiber optic transmission systems, optical and magnetic data storage systems, where the corruption of data being transferred between any two points affects system reliability. As part of the Reed-Solomon error correcting process, redundancy is added to the transmitted data, such that upon receipt of a data transmission the possibly corrupt data and redundancy are mathematically processed to correct errors in the data transmission. Prior art Reed-Solomon decoders use both Berlekamp/Massey and Chien Search processes to detect and correct the errors that 30 are present in the data transmission. These prior art Reed-Solomon decoders are primarily concerned with the total number of computations required to perform the data transmission decoding process, and the amount of hardware required to perform the data transmission decoding process. The Berlekamp/Massey synthesis process includes an erasure pre-shifting burden which adds to the processing complexity. These prior art Reed-Solomon decoders typically lack explicit early indication of error locations and do not provide early erasure information from the Berlekamp/Massey and Chien Search processes.

Solution

The above described problems are solved and a technical advance achieved by the pipelined high speed Reed-Solomon error/erasure decoder of the present invention which processes multiple code words in a pipelined fashion. The pipelined 5 high speed Reed-Solomon error/erasure decoder processes Reed-Solomon encoded data words to detect the presence of data words that have been corrupted in a digital system and processes corrupted data, that comprises both errors as well as erasures, through a simple iterative modified syndrome process. The iterative nature of this 10 method provides for limited computational effort at each step of the pipeline. This allows the pipelined high speed Reed-Solomon error/erasure decoder to easily handle full or shortened Reed-Solomon codes, as well as parallel processing to achieve 15 higher data rates. The iterative modified syndrome process is one of the pipelined steps. It relieves the erasure pre-shifting burden from the Berlekamp/Massey synthesis process, which reduces the number of cycles required at that stage of 20 processing. The pipelined high speed Reed-Solomon error/erasure decoder then proceeds classically with a Chien Search for any remaining error locations. This approach allows the pipelined high speed Reed-Solomon error/erasure decoder to relay early information on all error locations. The final stage of the decoding process is a parallel, iterative solution to Forney's equation for the calculation of the error magnitudes.

This pipelined high speed Reed-Solomon error/erasure decoder emphasizes the number of iterations (or clock cycles) and the number of combinatorial operations between each hardware register, which is accomplished by combining iterative LFSR solutions for syndrome modification and error magnitude processing to the well known 25 Berlekamp/Massey and Chien Search iterative hardware solutions. Additionally, in augmenting the known erasure locations with a classic Berlekamp/Massey - Chien Search for any remaining error locations, the pipelined high speed Reed-Solomon error/erasure decoder also provides explicit early indication of all error locations. This can be helpful in providing early erasure information for errors that no erasure 30 location was provided.

Brief Description of the Drawings

Figure 1 illustrates in block diagram form the pipelined high speed Reed-

Solomon error/erasure decoder of the present invention;

Figure 2 illustrates in block diagram form the Error Locator Coefficient Generator (Sigma Processor)

Figure 3 illustrates in block diagram form the topology of the Modified Syndrome Processor hardware shift register; and

Figure 4 illustrates in block diagram form the circuit construction of the Errata Value Processor for generating each of the error magnitudes.

Detailed Description

In the encoding of an (n, k) Reed-Solomon code, k data symbols are processed for each $n-k = r$ redundancy symbols. The maximum number of symbols in the code word, which are developed by appending the k data symbols to the r redundancy symbols, is determined by the size of the Galois Field that the Reed-Solomon code is based on. This finite field, known as $GF(2^m)$, is defined by a primitive polynomial with order $n = 2^m - 1$. Each redundancy symbol is an element α^i of the field $GF(2^m)$. The number of symbols in the data transmission data word that a code can correct is equal to the number of redundancy symbols (r). The minimum distance $d = r + 1$ of a redundancy code defines the minimum number of symbols for which every possible code word must differ. Each redundancy symbol can be used mathematically to either find the location or the magnitude of a symbol in error. Consequently, it takes two redundancy symbols to both locate and correct a single error in the data transmission.

Philosophy of the Pipelined High Speed Reed-Solomon Error/erasure Decoder

A Reed-Solomon decoder should handle corrupted data that comprises both erasures and errors to be effective in correcting data transmissions. When the location of corrupted data is known by any means that is external to a decoding process, it is called an erasure (e), and when the location of corrupted data is not known to the decoding process it is referred to as an error (t). Considering the minimum distance (r) of the redundancy code, for (r) symbols to be corrected, the location of each corrupted data byte must be known. This gives a code constraint of $(2t + e \leq d - 1)$ for an erasure/error correcting Reed-Solomon decoder.

The pipelined high speed Reed-Solomon error/erasure decoder 100 starts by calculating, in a syndrome generator 101, the partial syndromes of the received data

word $v(x) = c(x) + e(x)$, where $c(x)$ is the encoded word made up of k data symbols and r redundancy symbols, and $e(x)$ is the error word. Since $c(x)$ is a multiple of the generator polynomial $G(x)$, it drops out of the calculation of the partial syndromes, and the syndrome calculations become equivalent to evaluating the error polynomial at the 5 roots of the generator polynomial $G(x)$:

$$S_j = v(x) \Big|_{x = \alpha^j} = e(x) \Big|_{x = \alpha^j} = \sum_{i=1}^{2t} Y_i X_i^j$$

In the case where both errors and erasures are considered by the Reed-Solomon decoding process, the syndrome includes the transform for both the (t) errors and (e) erasures:

$$10 \quad S_j = \sum_{i=1}^e Y_i X_i^j + \sum_{k=1}^t V_k U_k^j$$

With the (e) known erasure locations, the pipelined high speed Reed-Solomon error/erasure decoder 100 then seeks to find up to (t) remaining errors. This requires that the transform syndromes S_j be modified by a modified syndrome processor 102 to factor out the effect of the (e) erasure locations. The (e) erasure locations are first 15 used to form the coefficients of the associated erasure locator polynomial:

$$\sigma(X) = \prod_{i=1}^e (X + U_i)$$

These coefficients are then processed in an iterative fashion to create the remaining modified transform syndromes T_j :

$$20 \quad T_j = \sum_{k=0}^e (-1)^k \sigma_k S_{j-k}; j = e+1, e+2, \dots, d-1$$

The modified transform syndromes T_j can then be used in the classic Berlekamp/Massey 103 and Chien Search 104 iterative solutions to again find up to (t) errors that remain in the data transmission. The (t) newly discovered error locations are combined with the original (e) erasure locations to form the entire

explicit set of error locations $\{X_j\}$. The coefficients of the final error locator polynomial for this set of error locations are then constructed as before, except that the polynomial is created for $(t + e)$ erasure and error locations.

$$5 \quad \sigma(X) = \prod_{j=1}^{(v-e)} (X + X_j)$$

The coefficients of $\sigma(X)$ are related to the erasure and error locations by the elementary symmetric functions σ_j . Together with the original syndromes, Forney's equation for the error magnitudes $\{E_i\}$ can be solved:

$$E_i = \frac{\sum_{j=0}^{v-1} \sigma_j S_{v-i}}{\sum_{j=0}^{v-1} \sigma_j X_j}, \text{ where } \sigma_j = \sigma_i + X_j \sigma_{j(i-1)}$$

10 Many decoding circuits for Reed-Solomon codes consider erasure pointers, but as disclosed in U.S. Patent No. 5,379,305 (Lih-Jyh Weng), the decoder modifies the original transform syndromes for $(p + e)$ erasures according to assumed pre-calculated coefficients. The pipelined high speed Reed-Solomon error/erasure decoder 100 provides a simple recursive hardware solution to this problem. It is
 15 based on an iterative solution to the elementary symmetric functions related to $\sigma(X)$. This solution shifts recursively for each known erasure location, according to the recursion:

$$\sigma_i(x) = \sigma_{i-1} + X_i \sigma_{i-1}, \text{ where } \sigma_0(x) = 1$$

20 The recursion shifts to the highest possible order, shifting with zero for any missing erasure locations. In this way, the circuit always has the least significant coefficient ($\sigma_0 = 1$) in the same significant position, regardless of the number of erasure locations presented. Additionally, the pipelined high speed Reed-Solomon error/erasure decoder 100 provides a parallel hardware solution that shifts the original
 25 syndromes in a barrel shift fashion for each modified syndrome, according to the

aforementioned equation for T_j .

Similarly, the process of determining the error magnitudes requires the coefficients of the combined error locator polynomial $\sigma(X)$. In the iterative solution of the above-noted U.S. Patent No. 5,379,305, these coefficients are again needed. The 5 pipelined high speed Reed-Solomon error/erasure decoder 100, again, solves the above recursion for $\sigma_i(X)$. Then as a natural extension of this recursion, applies a similar hardware shift register approach to the coefficients required in the numerator and denominator of Forney's solution for the error magnitudes $\{E_j\}$:

10
$$\sigma_{ji} = \sigma_i + X_j \sigma_{j(i-1)}$$

The coefficients are retained in a shift register during the generation of the numerator, and used in a similar fashion to generate the denominator. The spirit of the pipelined high speed Reed-Solomon error/erasure decoder 100 differs from 15 previous error evaluators such as that of U.S. Patent No. 5,430,739 (Shyue-Win Wei, et al.). In this approach a parallel solution to determinants is used to solve the error evaluator problem. This requires fewer clock cycles, but greater combinatorial complexity between each hardware register stage.

Description of the Preferred Embodiment

20 Fig. 1 depicts the complete pipelined high speed Reed-Solomon error/erasure decoder 100 with erasure capability. The first block comprises a buffer memory 108 that stores the code words of the received data transmission. These code words are also applied to the Syndrome Generator 101 which generates the transform syndromes according to:

25

$$S_j = v(x) \Big|_{x = \alpha^j} = e(x) \Big|_{x = \alpha^j} = \sum_{i=1}^{2t} Y_i X_i^j$$

This is a well known process, that yields $(2t)$ syndrome values which are output 30 on data path 113. The erasure pointers 112 are simply a digital indication that the code word symbol being received has been determined to contain an erasure location. This gives rise to the actual erasure locations 114 being presented to the

successive Modified Syndrome process 102.

The Modified Syndrome process 102 modifies the original $(2t)$ syndromes according to the (e) erasure locations, producing up to $(2t)$ modified syndromes $\{T_j\}$, depending on the number of erasure locations, which are output on data path 117.

- 5 Any unnecessary modified syndromes are padded with zeros as they are passed to the Berlekamp/Massey LFSR process 103. The Berlekamp/Massey process 103 creates an error locator polynomial that represents the (t) error locations that remain in the data transmission, beyond the (e) known erasure locations. The coefficients of this polynomial are represented by the set $\{\alpha_i\}$ which is passed on data path 120.
- 10 The Berlekamp/Massey process 103 also retains the original syndromes and erasure locations passed to it. These are passed on data paths 118 and 119, respectively, to the following Chien Search process 104, where the roots of the error locator polynomial representing the (t) errors are found. The (t) error locations are then concatenated, by the Chien Search process 104, to the original (e) erasure locations.
- 15 The result is the entire set of corrupted data locations $\{X_j\}$ which are output on data path 122. The Berlekamp/Massey process 103 and Chien Search process 104 are not discussed in detail in this embodiment due to the fact that they are well documented in the literature.

Together with the original syndromes, the entire set of corrupted data locations $\{X_j\}$ are sent on data paths 121, 122, respectively to the Sigma Processor 105. Here the corrupted data locations are used to create the coefficients of the associated corrupted data locator polynomial $\{\alpha_k\}$. These coefficients, together with the original syndromes and the full set of corrupted data locations $\{X_j\}$ are sent on data paths 123, 124, 125, respectively, to the Errata Value Processor 106, where an associated error magnitude $\{E_j\}$ is created for each respective erasure and error location that corresponds to the corrupted data.

With all the corrupted data locations $\{X_j\}$ and corrupted data magnitudes $\{E_j\}$ defined and output on data paths 126, 127, respectively, the original corrupted code word $C(x) = c(x) + e(x)$ is retrieved from buffer memory 108, used to buffer the associated pipelined delay of the pipelined high speed Reed-Solomon error/erasure decoder 100, and corrected in each location X_j with the value E_j by Error Corrector 107. The result is a corrected version of the corrupted code word $C(x)$ output on data

path 128.

Corrupted Data Locator Coefficient Generator (Sigma Processor)

In Figure 2, the error location "X" register 201 of the corrupted data locator coefficient generator 200 is loaded with the set of error locations $\{X_i\}$, for either 5 erasures and/or errors. The "σ" register circuit 202 is initialized with " $\sigma^0=1$ " in the most significant position, σ_n , and zero in all other less significant register positions. The "σ" register circuit 202 is shifted until a " $\sigma^0=1$ " appears in the σ_0 register position. This may mean that the "σ" register circuit 202 shifts for more cycles than there are 10 available error locations. In this case, the error location register 201 simply shifts zeros into the σ construction. Ultimately, this corrupted data locator coefficient generator 200 is solving the recursion:

$$\sigma_i(X) = \sigma_{i-1} + X_i \sigma_{i-1}, \text{ where } \sigma_0(X) = 1$$

15 This corrupted data locator coefficient generator 200 is used to provide corrupted data locator coefficients $\{\sigma\}$, for both the Modified Syndrome Processor 102 and the Sigma Processor 105 of Figure 1.

Each finite field multiplier is denoted by a circle with a dot in the middle. Likewise, each finite field adder is denoted by a circle with an addition or "+" sign 20 contained within. The addition is simple modulo 2, per bit, while the multiplication is the classic multiplication of two finite field values modulo $g(x)$ (where $g(x)$ is the primitive polynomial which defines the finite field $GF(2^m)$.) These mathematical operations are defined the same throughout this document.

Modified Syndrome Processor

25 Figure 3 shows the topology of the Modified Syndrome Processor 102 hardware shift register of the pipelined high speed Reed-Solomon error/erasure decoder 100. In this circuit, the bank of σ registers is the set of coefficients generated by the corrupted data locator coefficient generator 200. These coefficients are based on the set of erasure locations for which the original syndromes are to be modified. 30 The original syndromes are modified according to the following equation:

$$T_j = \sum_{k=0}^e (-1)^k \sigma_k S_{j-k}; j = e+1, e+2, \dots, d-1$$

The register 302 having register positions denoted with "S_n" are loaded with the (2t) original syndromes. The order of polynomial in the "σ" register is (e+1), dictated by the number of erasures (e). The circuit shifts for each "j = e+1, e+2, d-1". For 5 each clock cycle, the original syndrome register is shifted from right to left, and is shown to shift in an end around fashion only so that the original syndromes remain in the register and are not lost. On each cycle, a newly modified syndrome value is shifted into the register 303 having register positions denoted "T_j".

Ultimately, the Modified Syndrome Process 102 is comprised of generating the 10 error locator coefficients associated with (e) erasures, and then using these coefficients to modify the original (2t) syndromes. The modified syndromes can then be used in a Berlekamp/Massey process 103 and Chien Search process 104 to find up to (t) remaining errors.

Error Magnitude Generator (Errata Value Processor)

15 Figure 4 shows the circuit construction of the Errata Value Processor 106 for generating each of the error magnitudes {E_j}. The same circuit can be used to generate each of the (j=2t) possible error locations, or (2t) of these processors can be constructed so that all (j=2t) possible error magnitudes can be calculated in parallel. In the parallel case, the syndrome register denoted "S_i" can be shared for 20 all (2t) processors.

The first step in processing the error magnitudes is to generate the coefficients of the error locator polynomial {σ_k} associated with the ultimate set of error locations {X_j}. These coefficients are, again, calculated using the Error Locator Coefficient Generator circuit of Figure 2. These coefficients are then loaded into the σ_j register 25 401 of Figure 4. The syndrome {S} register 402 is loaded with the original (2t) syndromes, and the {X_j} register 403 is loaded with the respective error location for the given error magnitude. The (N_j) numerator 404 and (D_j) denominator 405 registers are loaded with zero, while the X^m register 406 is loaded with α⁰=1.

For the first (t) cycles, the σ_j registers shift left, while the σ_{j0} register position 30 gets the output of "Mux". The output of "Mux" 407 is the adder output until the last

numerator shift ($t = \text{num_cycle_n}$), where the $\alpha^0=1$ result is shifted into the σ_{j0} register position. Also, for each numerator (t) numerator cycles, the syndrome $\{S_i\}$ register 402 is shifted right one position. This defines the numerator result (N_i), and the values σ_{ji} .

5 For the second (t) cycles, the σ_{ji} registers shift right, and combine with the result of the X_j^m register 403, which shifts together with (D_i) for each of the (t) denominator cycles. This defines the denominator result (D_i). After the ($2t$) cycles, the final result $\{E_i\} = (\text{Num}/\text{Den}_i)$ is accomplished via a combinatorial invert and multiply.

10

Summary

15 The pipelined high speed Reed-Solomon error/erasure decoder processes multiple code words in a pipelined fashion. The pipelined high speed Reed-Solomon error/erasure decoder processes Reed-Solomon encoded words that have been corrupted in a digital system. The pipelined high speed Reed-Solomon error/erasure decoder processes errors as well as erasures through a simple iterative modified syndrome process. The iterative nature of this processing method provides for limited computational effort at each step of the pipeline. This allows the pipelined high speed Reed-Solomon error/erasure decoder to easily handle full or shortened Reed-Solomon codes, as well as parallel processing to achieve higher data rates.

What is Claimed:

1. A system for detecting and correcting both erasures and errors that are contained in a data transmission that includes multiple error correcting codes to identify said both erasures and errors, comprising:
 - means for storing said data transmission;
 - 5 means, responsive to said received data transmission, for generating syndrome data indicative of said erasures contained in said data transmission;
 - means, responsive to said received data transmission and said generated syndrome data, for generating data representative of error and erasure locations in said data transmission;
 - 10 means, responsive to said original syndromes and said error and erasure locations, for creating an associated error and erasure magnitude for each respective error and erasure location in said data transmission; and
 - means, responsive to said error and erasure locations, said error and erasure magnitudes, and said data transmission, for correcting each said both erasures and
 - 15 errors contained in said data transmission.
2. The system for detecting and correcting both erasures and errors that are contained in a data transmission of claim 1, wherein said means for generating syndrome data comprises:
 - means for producing a digital indication that the code word symbol of said data transmission being received has been determined to contain an erasure; and
 - 5 means, responsive to said digital indication, for modifying said digital indication to identify locations of said erasure in said code word symbol.
3. The system for detecting and correcting both erasures and errors that are contained in a data transmission of claim 1, wherein said means for generating data comprises:
 - means for creating an error locator polynomial that represents said errors contained in said data transmission;
 - 5 means for determining roots of said error locator polynomial representing said

errors; and

means, responsive to said error locator polynomial, for creating data indicative of error locations of said error in said data transmission.

4. The system for detecting and correcting both erasures and errors that are contained in a data transmission of claim 3 wherein said means for creating an error locator polynomial comprises:

means for executing an Berlekamp/Massey process to create an error locator
5 polynomial that represents said errors contained in said data transmission.

5. The system for detecting and correcting both erasures and errors that are contained in a data transmission of claim 3 wherein said means for determining roots comprises:

means for executing a Chien Search process to determine roots of said error
5 locator polynomial.

6. The system for detecting and correcting both erasures and errors that are contained in a data transmission of claim 3 wherein said means for creating data indicative of error locations comprises:

means for executing a Sigma process on said determined roots of said error
5 locator polynomial.

7. The system for detecting and correcting both erasures and errors that are contained in a data transmission of claim 1, wherein said means for correcting comprises:

means for reading code words of said data transmission from said means for
5 storing;

means for identifying each said error and erasure location and a corresponding
said error and erasure magnitude in said code words, as said code words are read
from said means for storing; and

means for correcting each said both erasures and errors contained in said code
10 words in said data transmission using said error and erasure location and a

corresponding said error and erasure magnitude.

8. The system for detecting and correcting both erasures and errors that are contained in a data transmission of claim 1 wherein said means for generating syndrome data comprises:

means for generating a set of syndrome data indicative of at least one erasure
5 contained in said data transmission;

means for modifying said set of syndrome data to generate error locator
coefficients associated with said at least one erasure; and

means for using said error locator coefficients to modify said set of syndrome
data.

9. The system for detecting and correcting both erasures and errors that are contained in a data transmission of claim 8 wherein said means for generating syndrome data further comprises:

means for interactively activating said means for generating a set of syndrome
5 data and said means for modifying said set of syndrome data and said means for
using to correct a plurality of erasures contained in said data transmission.

10. A method for detecting and correcting both erasures and errors that are contained in a data transmission that includes multiple error correcting codes to identify said both erasures and errors, comprising the steps of:

storing said data transmission in a memory;
5 generating, in response to said received data transmission, syndrome data
indicative of said erasures contained in said data transmission;

generating, in response to said received data transmission and said generated
syndrome data, data representative of error and erasure locations in said data
transmission;

10 creating, in response to said original syndromes and said error and erasure
locations, an associated error and erasure magnitude for each respective error and
erasure location in said data transmission; and

correcting, in response to said error and erasure locations, said error and

15 erasure magnitudes, and said data transmission, each said both erasures and errors contained in said data transmission.

11. The method for detecting and correcting both erasures and errors that are contained in a data transmission of claim 10, wherein said step of generating syndrome data comprises:

5 producing a digital indication that the code word symbol of said data transmission being received has been determined to contain an erasure; and

modifying, in response to said digital indication, said digital indication to identify locations of said erasure in said code word symbol.

12. The method for detecting and correcting both erasures and errors that are contained in a data transmission of claim 10, wherein said step of generating data comprises:

5 creating an error locator polynomial that represents said errors contained in said data transmission;

determining roots of said error locator polynomial representing said errors; and

creating, in response to said error locator polynomial, data indicative of error locations of said error in said data transmission.

13. The method for detecting and correcting both erasures and errors that are contained in a data transmission of claim 12 wherein said step of creating an error locator polynomial comprises:

5 executing an Berlekamp/Massey process to create an error locator polynomial that represents said errors contained in said data transmission.

14. The method for detecting and correcting both erasures and errors that are contained in a data transmission of claim 12 wherein said step of determining roots comprises:

5 executing a Chien Search process to determine roots of said error locator polynomial.

15. The method for detecting and correcting both erasures and errors that are contained in a data transmission of claim 12 wherein said step of creating data indicative of error locations comprises:

5 executing a Sigma process on said determined roots of said error locator polynomial.

16. The method for detecting and correcting both erasures and errors that are contained in a data transmission of claim 10, wherein said step of correcting comprises:

5 reading code words of said data transmission from said means for storing; identifying each said error and erasure location and a corresponding said error and erasure magnitude in said code words, as said code words are read from said memory; and

10 correcting each said both erasures and errors contained in said code words in said data transmission using said error and erasure location and a corresponding said error and erasure magnitude.

17. The method of detecting and correcting both erasures and errors that are contained in a data transmission of claim 10 wherein said step of generating syndrome data comprises:

5 generating a set of syndrome data indicative of at least one erasure contained in said data transmission; modifying said set of syndrome data to generate error locator coefficients associated with said at least one erasure; and using said error locator coefficients to modify said set of syndrome data.

18. The method of detecting and correcting both erasures and errors that are contained in a data transmission of claim 10 wherein said step of generating syndrome data further comprises:

5 interactively activating said step of generating a set of syndrome data and said step of modifying said set of syndrome data and said step of using to correct a plurality of erasures contained in said data transmission.

19. A system for detecting and correcting both erasures and errors that are contained in a data transmission that includes multiple error correcting codes to identify said both erasures and errors, comprising:

- means for storing said data transmission;
- 5 means, responsive to said received data transmission, for producing a digital indication that the code word symbol of said data transmission being received has been determined to contain an erasure;
- means, responsive to said digital indication, for modifying said digital indication to identify locations of said erasure in said code word symbol;
- 10 means, responsive to said received data transmission and said modified digital indication, for generating data representative of error and erasure locations in said data transmission;
- means, responsive to said original syndromes and said error and erasure locations, for creating an associated error and erasure magnitude for each respective error and erasure location in said data transmission; and
- 15 means, responsive to said error and erasure locations, said error and erasure magnitudes, and said data transmission, for correcting each said both erasures and errors contained in said data transmission, comprising:
- means for reading code words of said data transmission from said means for storing;
- 20 means for identifying each said error and erasure location and a corresponding said error and erasure magnitude in said code words, as said code words are read from said means for storing; and
- means for correcting each said both erasures and errors contained in said code words in said data transmission using said error and erasure location and a corresponding said error and erasure magnitude.

25

20. The system for detecting and correcting both erasures and errors that are contained in a data transmission of claim 19, wherein said means for generating data comprises:

- means for creating an error locator polynomial that represents said errors

5 contained in said data transmission;
means for determining roots of said error locator polynomial representing said errors; and
means, responsive to said error locator polynomial, for creating data indicative of error locations of said error in said data transmission.

21. The system for detecting and correcting both erasures and errors that are contained in a data transmission of claim 20 wherein said means for creating an error locator polynomial comprises:
means for executing an Berlekamp/Massey process to create an error locator
5 polynomial that represents said errors contained in said data transmission.

22. The system for detecting and correcting both erasures and errors that are contained in a data transmission of claim 20 wherein said means for determining roots comprises:
means for executing a Chien Search process to determine roots of said error
5 locator polynomial.

23. The system for detecting and correcting both erasures and errors that are contained in a data transmission of claim 20 wherein said means for creating data indicative of error locations comprises:
means for executing a Sigma process on said determined roots of said error
5 locator polynomial.

24. A method for detecting and correcting both erasures and errors that are contained in a data transmission that includes multiple error correcting codes to identify said both erasures and errors, comprising the step of:
storing said data transmission in a memory;
5 producing, in response to said received data transmission, a digital indication that the code word symbol of said data transmission being received has been determined to contain an erasure;
modifying, in response to said digital indication, said digital indication to

identify locations of said erasure in said code word symbol;

10 generating, in response to said received data transmission and said modified digital indication, data representative of error and erasure locations in said data transmission;

15 creating, in response to said original syndromes and said error and erasure locations, an associated error and erasure magnitude for each respective error and erasure location in said data transmission; and

correcting, in response to said error and erasure locations, said error and erasure magnitudes, and said data transmission, each said both erasures and errors contained in said data transmission, comprising:

20 reading code words of said data transmission from said means for storing;

identifying each said error and erasure location and a corresponding said error and erasure magnitude in said code words, as said code words are read from said memory; and

25 correcting each said both erasures and errors contained in said code words in said data transmission using said error and erasure location and a corresponding said error and erasure magnitude.

25. The method for detecting and correcting both erasures and errors that are contained in a data transmission of claim 24, wherein said step of generating data comprises:

5 creating an error locator polynomial that represents said errors contained in said data transmission;

determining roots of said error locator polynomial representing said errors; and

creating, in response to said error locator polynomial, data indicative of error locations of said error in said data transmission.

26. The method for detecting and correcting both erasures and errors that are contained in a data transmission of claim 25 wherein said step of creating an error locator polynomial comprises:

executing an Berlekamp/Massey process to create an error locator polynomial

5 that represents said errors contained in said data transmission.

27. The method for detecting and correcting both erasures and errors that are contained in a data transmission of claim 25 wherein said step of determining roots comprises:

executing a Chien Search process to determine roots of said error locator
5 polynomial.

28. The method for detecting and correcting both erasures and errors that are contained in a data transmission of claim 25 wherein said step of creating data indicative of error locations comprises:

executing a Sigma process on said determined roots of said error locator
5 polynomial.

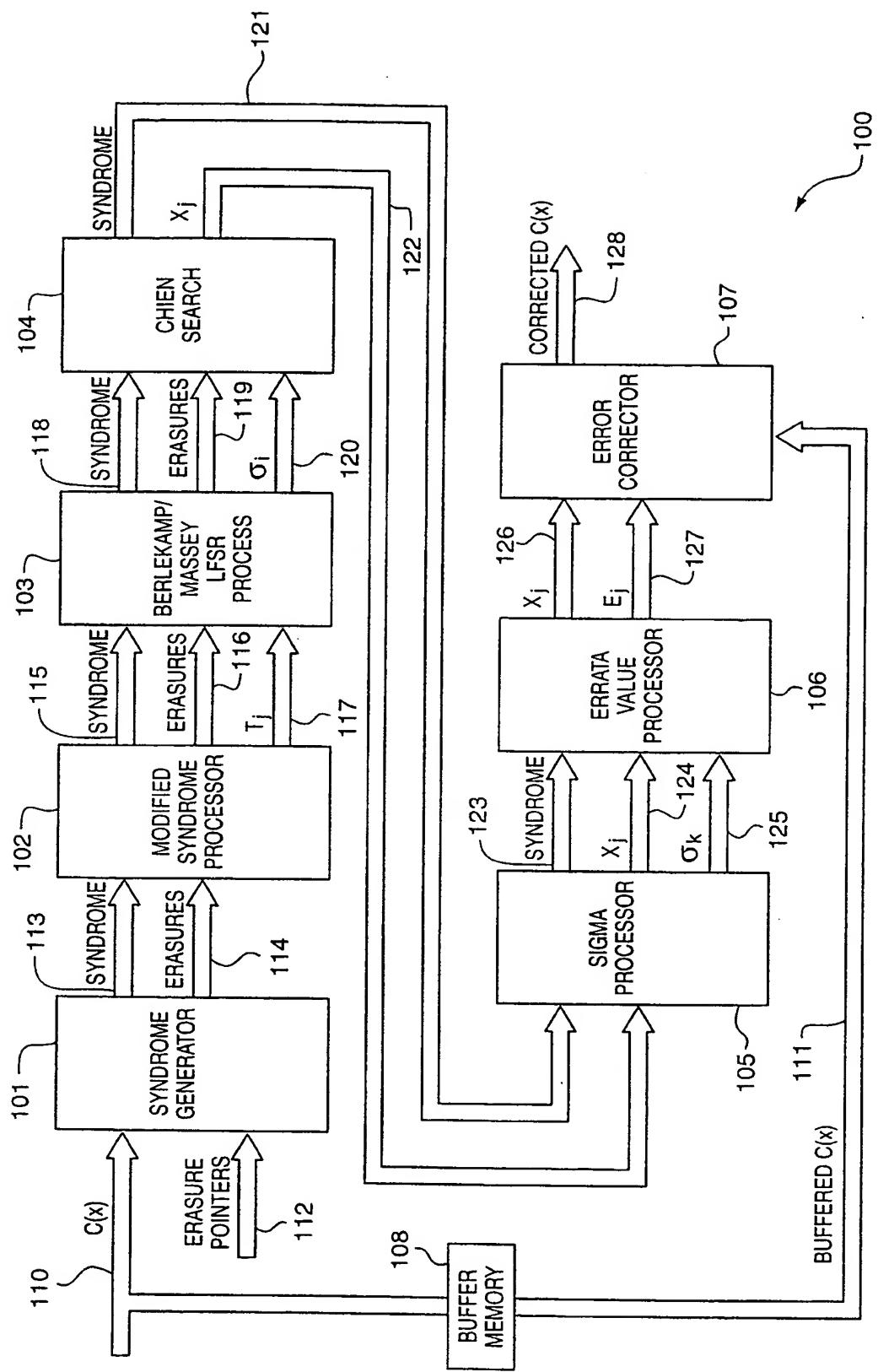


FIG. 1

2/4

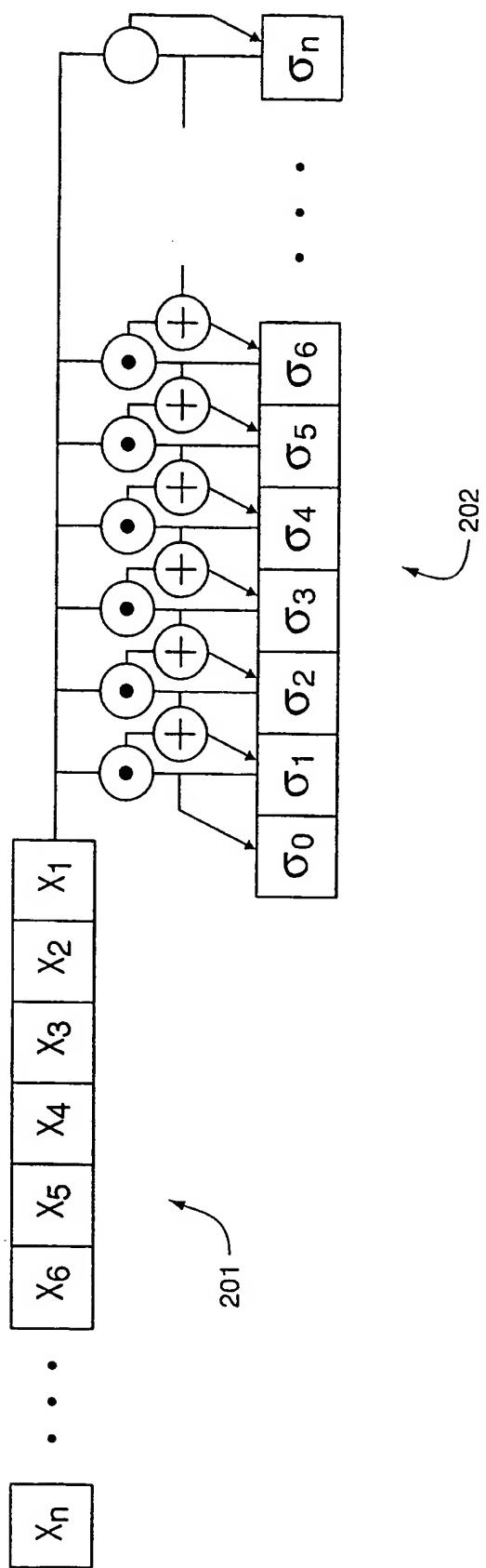


FIG. 2

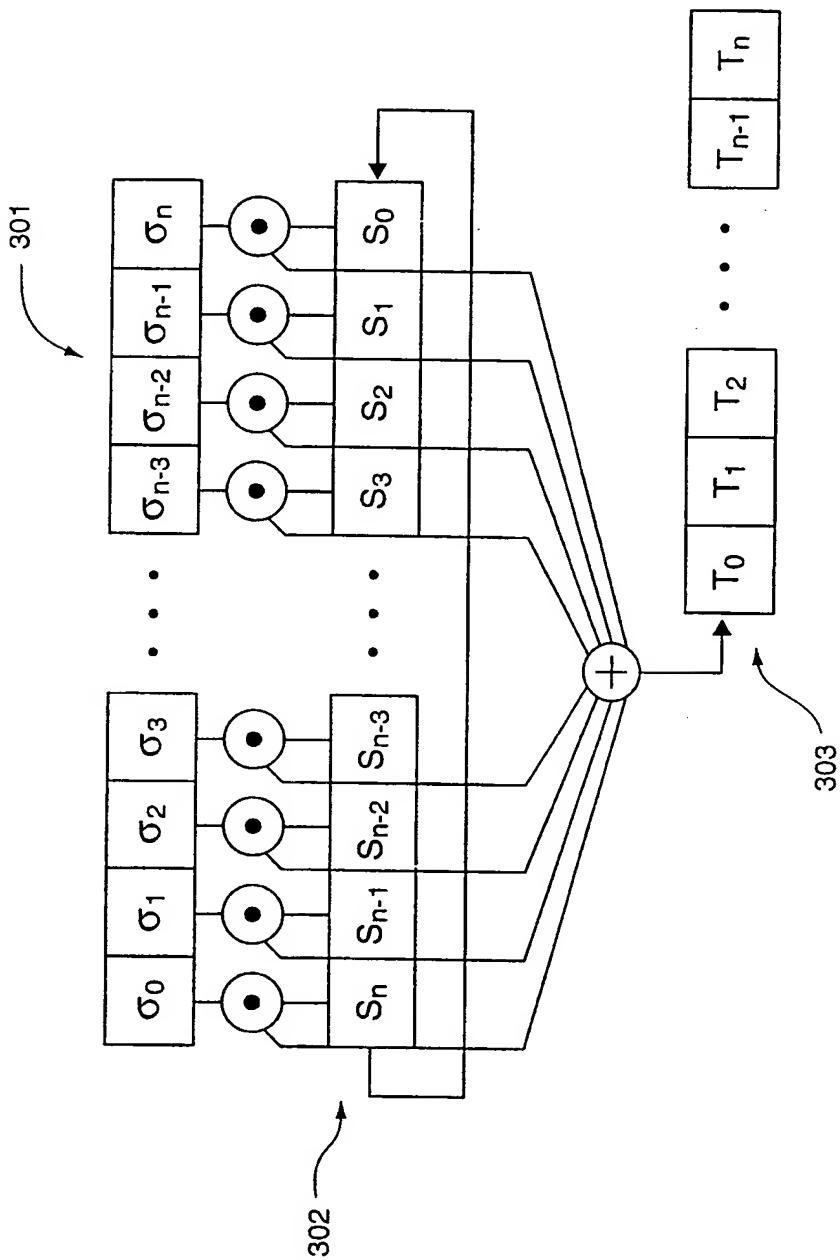


FIG. 3

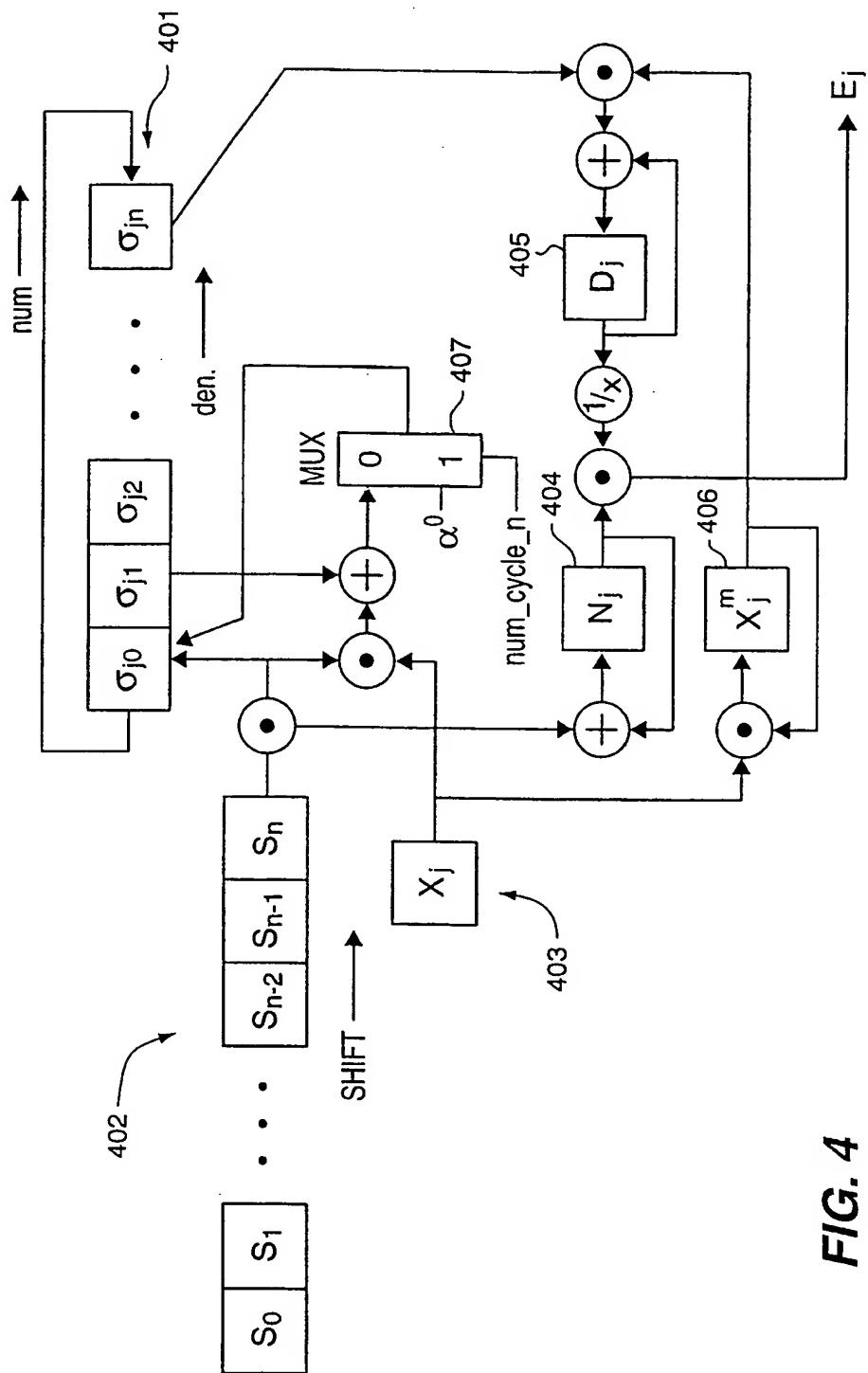


FIG. 4

INTERNATIONAL SEARCH REPORT

Int. Application No
PCT/US 00/07675

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H03M13/15

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H03M H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 379 305 A (WENG LIH-JYH) 3 January 1995 (1995-01-03) cited in the application abstract column 1, line 34 -column 2, line 41 column 3, line 24 -column 4, line 20 column 4, line 35 - line 45 column 5, line 52 -column 11, line 5 figures 3-9 ---	1-28
A	US 5 430 739 A (WEI SHYUE-WIN ET AL) 4 July 1995 (1995-07-04) cited in the application the whole document ---	1-28 -/-

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

* Special categories of cited documents :

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority, claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- "&" document member of the same patent family

Date of the actual completion of the international search

1 August 2000

Date of mailing of the international search report

08/08/2000

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Barel-Fauchoux, C

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/07675

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	BLAUM M ET AL: "NEW ARRAY CODES FOR MULTIPLE PHASED BURST CORRECTION" IEEE TRANSACTIONS ON INFORMATION THEORY, US, IEEE INC. NEW YORK, vol. 39, no. 1, 1993, pages 66-77, XP000339376 ISSN: 0018-9448 the whole document -----	1-28

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 00/07675

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US 5379305 A 03-01-1995	DE	4324299	A	27-01-1994
	GB	2269034	A, B	26-01-1994
	JP	6188746	A	08-07-1994
	NL	9301240	A	16-02-1994
US 5430739 A 04-07-1995	US	5440570	A	08-08-1995